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Introduction

This report describes research done in the final year (and one year no cost extension) under the NAS/NASA-Ames Consortium Agreement NCC 2-717. The main thrust of the work involved direct volume visualization of large curvilinear volumes created by computational fluid dynamics simulations. As we proposed in the original request, we particularly investigated during this period the use of multi-resolution data structures to allow comfortably fast visualization of large and complex data sets, and rendering algorithms general enough to accommodate a variety of irregular grid types, including multi-grids. These activities are described in somewhat greater detail below. Publications produced under the auspices of this grant include:

1. Wilhelms, Jane, and Allen Van Gelder, 1994. "Multi-dimensional Trees for Controlled Volume Rendering and Compression," 1994 ACM Symposium on Volume Visualization, pp. 27–34, October, 1994. [WVG94].
2. Van Gelder, Allen and Jane Wilhelms, 1994. "Topological Considerations in Isosurface Generation," *ACM Transactions on Graphics*, Vol. 13, No. 4, October 1994, pg. 337–375. [VGW94].
3. Wilson, Orion, Allen Van Gelder, and Jane Wilhelms, 1994. "Direct Volume Rendering via 3D Textures," UCSC Technical Report UCSC-CRL-94-19. [WVGW94].
4. Kim, Kwansik, Allen Van Gelder, and Jane Wilhelms, 1995. "Hierarchical Volume Rendering Using Ray Casting", UCSC Technical Report UCSC-CRL-94-19. [KGW95].
5. Wilhelms, Jane, Paul Tarantino, and Allen Van Gelder, "A Scan-Line Algorithm for Volume Rendering of Multiple Curvilinear Grids", UCSC Technical Report UCSC-CRL-95-57. [WTVG95].

The grant also provided support for graduate students, summer salary for two faculty members (Jane Wilhelms and Allen Van Gelder), travel to conferences, and computer maintenance.

1 Multi-Dimensional (Hierarchical) Data Structures

We have studied the use of hierarchical data structures for faster and more flexible visualization of large data sets. In our initial work [WVG94], we implemented an octree structure over regular data sets. Each node of the hierarchy represents a region of the data, and children of any node represent subregions of the parent's data. The leaf nodes represent the exact data in the volume. Each node of the tree stores a "best-fit" trilinear model of the behavior of the data in the region represented by the node, and an error metric (usually mean squared error) between the nodal model and the actual data in the region. For direct volume rendering, we used coherent projection [WVG91] adapted for hierarchies. The user can specify an allowable error in the image. The program traverses the tree and renders the highest nodal region in any branch where the error in the nodal model is within the user-allowed error. Thus, a coarse fast or exact slower image can be seen, under the control of the user.

Originally, this method used a hierarchy over regular data sets, we have recently begun to develop a hierarchy over irregular data sets, which is a more difficult problem [WTVG95]. We have already implemented the basic hierarchy over irregular grids, but have not yet published it. We believe the combination of access to actual data values plus a regular hierarchical data structure will give us the best of both worlds and allow exact rendering when needed, and fast approximate rendering when acceptable. While we used the visualization approach known as direct volume rendering, we believe the hierarchical approach can be extended to other rendering methods as well.

2 Rendering Complex Multigrids

In the past, again supported by NASA, we have developed a new method for direct volume rendering of curvilinear grids at comfortable speeds [VGW93]. While we believe this is one of the best methods for rendering curvilinear volumes, providing a good trade-off between speed and image quality, it cannot handle the multiple grids sometimes seen in computational fluid dynamics, such as the nine grids of the space shuttle [BCFM+89]. We were looking for a very flexible rendering method that would accommodate these grids, other irregular grids, and the inclusion of polygon mesh surface data (which can greatly help in clarifying the image).

We have developed a scanline, face-projection method that provides these features, and can produce excellent quality images in a reasonable time [WTVG95]. This approach can handle curvilinear data sets, tetrahedral data sets, multiple intersecting data sets, and the inclusion of polygon mesh surfaces. It requires no graphics hardware (being done totally in software), and can produce images of the same quality as ray-casting but much faster, because of its use of coherence. We have parallelized the approach and are getting a speed-up of better than 3.25 on four processors. We are presently extending the technique for use in a multi-resolution hierarchy, to better accommodate very large data sets.

3 Other Results

We have also been exploring alternative methods for direct volume rendering, including hierarchical ray casting [KGW95], and the use of 3D texture mapping hardware on machines that provide this feature [WVGW94]. The latter, in particular, provides very good image quality and remarkable speeds, but so far has only been developed for use with regular grids.

4 Conclusions

We have provided new tools for rendering complex multi-gridded scalar data in reasonable time with good image quality. We have attached two publications central to our work during this period, "Multi-Dimensional Trees for Controlled Volume Rendering and Compression" [WVG94] and "A Scan-Line Algorithm for Volume Rendering of Multiple Curvilinear Grids" [WTVG95]. Images from our work can be viewed on the world wide web at http://www.cse.ucsc.edu/~wilhelms/scivi/index.html.

References

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[KGW95] Kwansik Kim, Allen Van Gelder, and Jane Wilhelms. Hierarchical volume rendering using ray casting. Technical Report UCSC-CRL-95-31, CIS Board, University of California, Santa Cruz, 1995.

[VGW93] Allen Van Gelder and Jane Wilhelms. Rapid exploration of curvilinear grids using direct volume rendering. Technical Report UCSC-CRL-93-02, University of California, Santa Cruz, UCSC CIS Department, Applied Sciences Building, Santa Cruz, CA 95064, 1993. (extended abstract in *Proc. IEEE Visualization 93*, Oct. 1993).

[VGW94] Allen Van Gelder and Jane Wilhelms. Topological considerations in isosurface generation. *ACM Transactions on Graphics*, 13(4), October 1994. Also UCSC technical report UCSC-CRL-90-14.

[WTVG95] Jane Wilhelms, Paul Tarantino, and Allen Van Gelder. A scan-line algorithm for volume rendering of multiple curvilinear grids. Technical Report UCSC-CRL-95-57, University of California, Santa Cruz, Santa Cruz, Ca 95064, 1995.

[WVG91] Jane Wilhelms and Allen Van Gelder. A coherent projection approach for direct volume rendering. *Computer Graphics (ACM Siggraph Proceedings)*, 25(4):275–284, 1991.

[WVG94] Jane Wilhelms and Allen Van Gelder. Multi-dimensional trees for controlled volume rendering and compression. In *ACM Symposium on Volume Visualization 1994*, Washington, D.C., October 1994. See also technical report UCSC-CRL-94-02.

[WVGW94] Orion Wilson, Allen Van Gelder, and Jane Wilhelms. Direct volume rendering via 3d textures. Technical Report UCSC-CRL-94-19, CIS Board, University of California, Santa Cruz, 1994.